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INJECTION MOLDING OF ELASTOMERS

TECHNICAL REPORT

By

J. D. Ruby

June 1967

U. S. ARMY WEAPONS COMMAND

ROCK ISLAND ARSENAL

RESEARCH & ENGINEERING DIVISION

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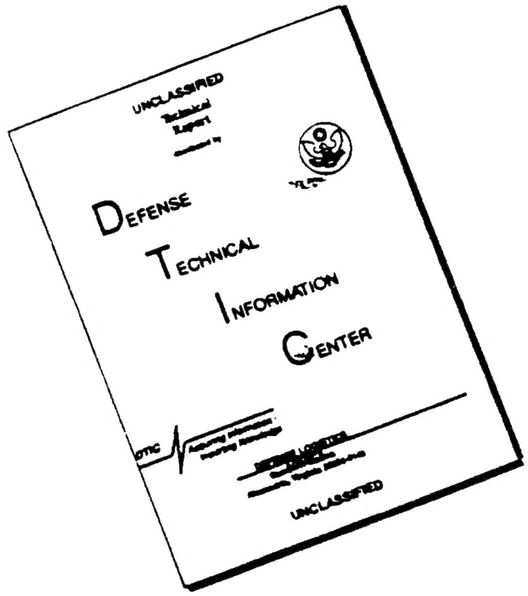

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Research Laboratories

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ABSTRACT

The injection molding process for elastomers was investigated for its applicability in the fabrication of end items for Army use.

A variety of elastomeric compounds was prepared and injection molded. Results indicate that most compounds which can be compression molded can also be injection molded. Rubber items having equivalent physical properties and dimensions were obtained from the two molding processes.

Injection molding reduces the time required for curing; eliminates the need to preform the rubber prior to molding; reduces the amount of mold handling; and lowers the rejection rate in comparison with compression molding.

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PROBLEM

To investigate the use and applicability of the injection molding process for elastomeric items used in Army equipment.

To determine whether properties of injection molded items are comparable to those of compression molded items and whether the same dimensional tolerances can be maintained in both processes.

BACKGROUND

The growing interest in the injection molding process for elastomers is due to its many advantages over compression molding, which include: less stock preparation, shorter cure cycles, less physical handling of molds, improved product uniformity, lower finishing and labor costs and lower rejection rates.[1,2]

In compression molding, a quantity of preformed stock is placed in a heated mold cavity, the mold is closed and pressure and heat applied which cause the compound to fill the cavity with any excess being forced out as flash.

In the injection molding process, the mold is closed and the rubber compound is then injected into the preheated mold with a source of pressure external to that applied to close the mold. The external pressure can be applied by a screw or ram. Ram type injection which can be continuously loaded and automatically controlled has been successfully used commercially for several years.

APPROACH

In order to determine the effect of mold temperature and cycle time on properties of injection molded items, a conventional type neoprene compound was cured at three different mold temperatures with cycle times ranging from 1/2 to 5 minutes.

Neoprene, nitrile and SBR compounds commonly used in the fabrication of Army end items, were compression and injection molded. Physical properties were determined in order to compare the two types of processing.

1. Z. J. Dorko, J. Timar, J. Walker, "Injection Molding, Compounding & Equipment," Rubber World, 148, 29-52, July 1963.
2. W. F. Watson and D. A. W. Izod, "Injection Molding of Rubber," Rubber World, Vol. 155, No. 5, February 1967.

A series of compounds was prepared to determine the effect on physical properties of several conventional curing systems when used with injection molding.

Compounds based on an SBR masterbatch were vulcanized with different cure systems in an attempt to reduce the injection molding cycle to one minute or less. Several polyurethane based compounds containing a coagent in a peroxide cure system were included in the study. The use of coagents with conventional peroxide curing systems has been found to have a beneficial effect on properties when used with certain base polymers.[3]

Injection molded compounds were developed to meet specific grade requirements of MIL-R-3065 and MIL-STD-417.

Bonding of rubber to metal was investigated to determine if special bonding procedures would be necessary when using the injection molding process.

Formulations for compounds used in this study are given in Table I. Compounds were mixed in an internal Banbury mixer with curatives added on a two roll mill.

Physical properties of compression molded rubber were obtained on standard 6 x 6 x 0.075 inch, ASTM tensile sheets cured in a 24 x 24 inch platen hydraulic press under 1000 psi. pressure.

Injection molding was accomplished with a 100 ton, vertical ram type machine with 14 x 14 inch platens, capable of delivering a 7-9 ounce shot. The cylinder and platens are steam and electrically heated respectively, while both ram and press are operated hydraulically. A front view is shown in Figure 1. The machine is capable of either manual or semi-automatic operation. Circular pads (0.1 inch thick x 5.5 inches in diameter) were molded for test. The pads were removed hot and air cooled. Molding and machine conditions are listed in the data tables.

All testing was carried out according to ASTM procedures.

3. John A. Williams, "Coagents for Improved Elastic Recovery in Polyester Urethane Elastomers," Rock Island Arsenal Technical Report 66-382.

TABLE I

COMPOUND FORMULATIONS

Ingredient	441-1	461F1	506-1	488	528-1	524-2	538-1	N154	N158	N158-2	S150	S150-1	S150-2	E6	E8-1	E8-2	G11-1	G11-2	S150-3	S150-4	S150-5	S150-6	S150-7	U27	U27-1	U27-2	U27-3	U27-4	S154-4
SBR 1500			50	100	100																								100
SBR 1023			50																										
SBR 1601											150	150	150						150	150	150	150	150						
Paracril AJ	100	100						100	100	100																			
Neoprene WD						100	100																						
Nordel 1070														100	100	100													
Silastic 740																	100	100											
Genthane SR																								100	100				
Genthane S																										100	100	100	
Zinc Oxide	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5			5	5	5	5	5						5
Cadmium Oxide																													
Magnesia						4	4																						
Stearic Acid	1	1	2	1	1			1	1	1	2	2	2	1	1	1			2	2	2	2	2	0.2	0.2	0.2	0.2	0.2	1
Agerite Resin D	1	1	1	1	1			1	1	1	1	1	1						1	1	1	1	1						1
Neozone D			1	1	1						1	1	1						1	1	1	1	1						1
Akroflex CD						3	3																						
Multrathane E164																								2.0	2.0				
Gastex		60					35	60	60	60																			
Statex 125						30																							
Philblack A	25		50																							25	25	25	
Philblack O														60	60	60								25	25				35
Kosmobile 77				40	30																								
P-33	75																												
Hi Sil 233		20															5	15											
Purecal					30																								
Flexol TOF		5		10	10																								10
DOS		5				20	30																						
TP-95	10							15	15	15																			
Flexol 4GO	5																												
Plasticizer SC		5																											
U.O.P. 88			3	4	3						3	3	3						3	3	3	3	3						3
Necton 60														20	20	20													
Helizone		2	1	1	1	3	3				1	1	1						1	1	1	1	1						1
Sulfur	1.5	1.5	1.75	1.5	1.5			0.5	1.5		1.75			2	0.5				2.0	0.5	2.5		1.75						2.0
Altax	1.5	1.5		1.75					1.5					1.5	1.0				0.5										
Santocure			1.0		1.5			1.0			1.0									2.0	1.5		1.0						1.5
Methyl Tuads								2.0							2.0														
NA-22						1.0	1.0																						
Di Cup 40C										4.0			4.0			6.0								4.0	4.0	4.0	4.0	4.0	
Methyl Selenac																			0.75										
Morfax																				1.5									
Ledate																					1.25								
Tetrone A												1.0										1.0							
Captax												1.0										1.0							
Tri Allyl Cyanurate																									2.0		2.0		
Di Allyl Adipate																												2.0	
Luperco 101XL																	0.4	0.4											

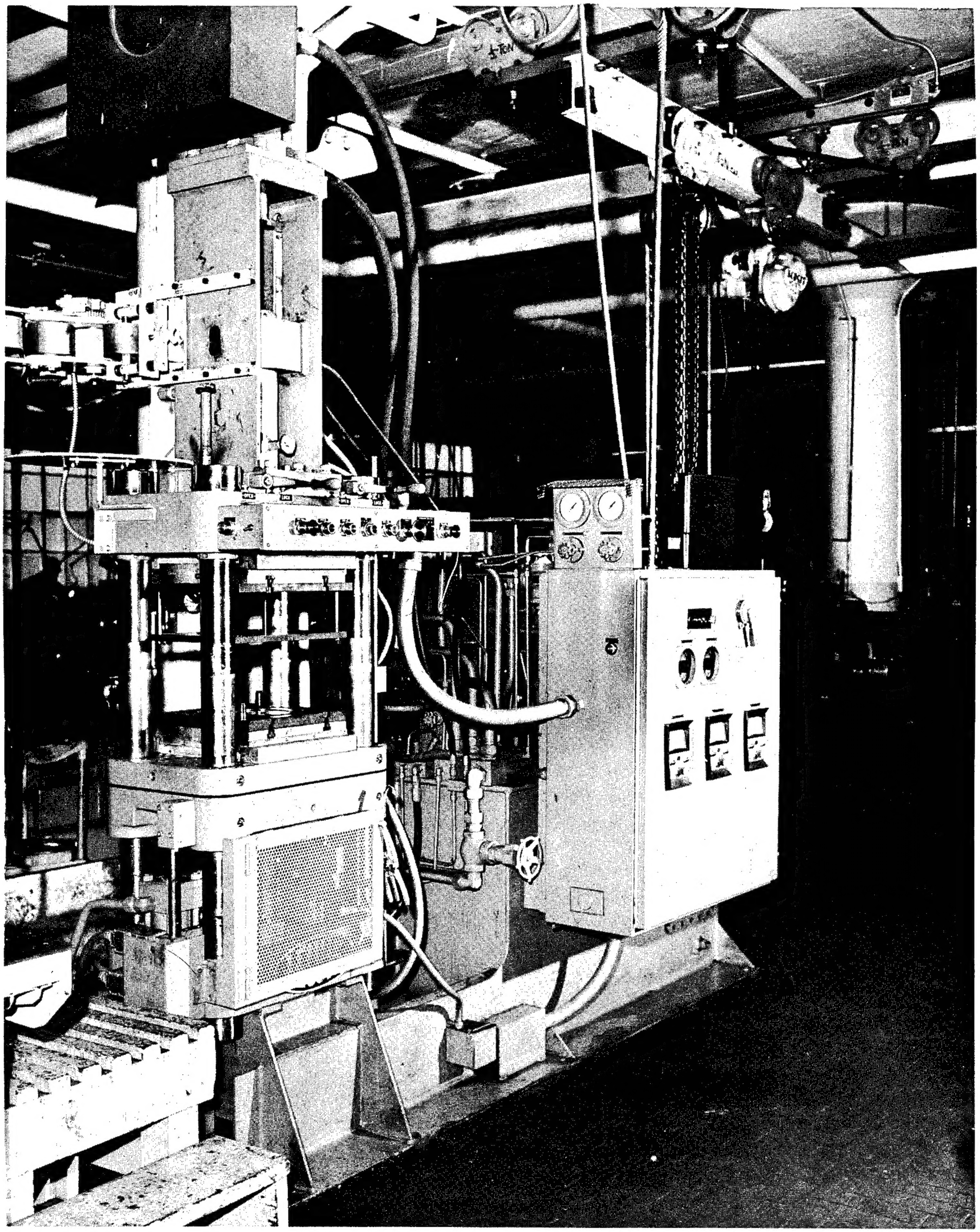

FIGURE 1 — INJECTION MOLDING MACHINE
100 TON, VERTICAL RAM TYPE

RESULTS AND DISCUSSION

Initial work showed that stress-strain properties of injection molded SBR, nitrile and neoprene compounds, cured with conventional curatives, did not change appreciably with mold temperature over the range 380 to 420^{o}F. nor with time from 1 minute to 5 minutes. Table II shows the effect of time and mold temperature on the properties of a neoprene compound (524-2).

Compounds of SBR, nitrile and neoprene were cured by both compression and injection molding. Table III presents a comparison of properties obtained on pads compression molded for 30 minutes at 307^{o}F. and injection molded 2 minutes at 400^{o}F.

Variations of injection cylinder temperature had a negligible effect on stress-strain properties but exhibited considerable influence on flow and end item appearance.

Table IV presents a comparison of properties obtained on compression and injection molded test pads of three different elastomers cured with conventional curing systems and of compression and injection molded silicone compounds with and without post cure. Results indicate that the over all properties of injection molded sulfur donor (methyl tuads) cured rubber are better than injection molded sulfur cured compounds. The ultra fast curing system of Tetrone A and Captax could not be controlled and premature curing took place in the nozzle.

Injection molding of peroxide cured compounds met with varying degrees of success. Silicone and EPDM compounds could be successfully injection molded at 400^{o}F. An SBR compound required a reduction in cure temperature to 350^{o}F. in order to obtain acceptable pieces. A compound based on NBR could not be injection molded at the reduced temperature of 350^{o}F. due to premature curing in the sprue and runner system. The successfully injection molded peroxide cured samples exhibited improved compression set values compared with sulfur or sulfur donor cure systems.

Post curing of compression and injection molded silicone elastomers produced no improvement in stress-strain properties and only slight improvement in compression set values.

Table V presents the data obtained on SBR compounds prepared in an attempt to reduce the injection cure cycle to one minute or less. Stress-strain properties for 1/2 minute injection molded samples compare favorably with

TABLE II

EFFECT OF CYCLE TIME AND MOLD TEMPERATURE ON
PROPERTIES OF A NEOPRENE RUBBER

Compound 524-2	Mold Temperature °F.														
	380					400					420				
Cycle Time, Min.	1	2	3	4	5	1	1-1/2	2	3	4	1/2	1	2	3	
Tensile psi	2190	2150	1880	2010	1980	2290	2110	2220	2120	1980	2190	2160	1690	1970	
Modulus @ 100% E "	210	210	230	210	220	230	220	230	220	230	170	210	210	210	
" 200% E "	520	590	610	610	630	570	630	590	600	600	500	580	660	590	
" 300% E "	1080	1210	1310	1380	1440	1490	1440	1260	1240	1310	1130	1290	1440	1360	
Elongation, %	445	410	355	355	370	395	370	405	390	365	430	400	325	375	
Hardness, Shore A	45	47	50	48	48	48	48	50	49	50	46	47	48	48	

Cylinder Temperature, °F 135

Inject Pressure, psi 1500
" Time, sec 6
Gate Diameter, in. .050

TABLE III

COMPARISON OF PROPERTIES - COMPRESSION VS. INJECTION MOLDING

		Press Cured 30 min. @ 307°F.	Injection Molded 2 min. @ 400°F.	Injection Molding Conditions
SBR 1500/SBR 1023		(508-1)		
Tensile	psi	2860	2440	Cylinder Temperature °F. 175
Modulus @ 300% E.	"	1920	1860	Injection Pressure, psi 1700
Elongation, %		435	400	" Time sec. 10
Hardness, Shore A		62	62	Gate Diameter in. .050
SBR 1500		(488)		
Tensile	psi	1870	1760	Cylinder Temperature °F. 175
Modulus @ 300 % E	"	450	330	Injection Pressure, psi 1200
Elongation, %		705	760	" Time sec. 8
Hardness, Shore A		44	45	Gate Diameter in. .050
SBR 1500		(528-1)		
Tensile	psi	1740	1210	Cylinder Temperature °F. 200
Modulus @ 300% E.	"	150	120	Injection Pressure, psi 1500
Elongation, %		960	945	" Time sec. 9.5
Hardness, Shore A		43	42	Gate Diameter in. .050
Neoprene		(524-2)		
Tensile	psi	2440	2220	Cylinder Temperature °F. 135
Modulus @ 300% E,	"	1530	1260	Injection Pressure, psi 1500
Elongation, %		370	405	" Time sec. 6
Hardness, Shore A		51	50	Gate Diameter in. .050
Neoprene		(538-1)		
Tensile	psi	1930	1990	Cylinder Temperature °F. 150
Modulus @ 300% E.	"	800	600	Injection Pressure, psi 800
Elongation, %		465	515	" Time sec. 5.7
Hardness, Shore A		42	37	Gate Diameter in. .050
NBR		(441-1)		
Tensile	psi	1490	1560	Cylinder Temperature °F. 180
Modulus @ 300% E.	"	1400	1060	Injection Pressure, psi 1500
Elongation, %		325	405	" Time sec. 9.5
Hardness, Shore A		63	58	Gate Diameter in. .050
NBR		(461F1)		
Tensile	psi	1630	1310	Cylinder Temperature °F. 170
Modulus @ 300% E.	"	800	1090	Injection Pressure, psi 1700
Elongation, %		495	405	" Time sec. 5.5
Hardness, Shore A		54	53	Gate Diameter in. .050

TABLE IV

COMPARISON OF COMPRESSION AND INJECTION MOLDED RUBBER CURED WITH THREE TYPES OF CURING SYSTEMS

Ethylene/Propylene Terpolymer

Type of Curing System	Sulfur E8 Compression 30"/307°F.	Sulfur E8 Injection 2"/400°F.	Sulfur Donor Methyl Tuads E8-1 Compression 30"/307°F.	Sulfur Donor Methyl Tuads E8-1 Injection 2"/400°F.	Peroxide E8-2 Compression 30"/307°F.	Peroxide E8-2 Injection 2"/400°F.	Injection Molding Conditions
Tensile psi	2000	2400	2770	3000	2070	1840	Cylinder Temperature °F. 200
Modulus @ 300% E. "	230	570	350	560	540	410	Inject Pressure psi 1100
Elongation, %	1090	1100	930	765	655	590	" Time sec 14
Hardness, Shore A	47	49	54	59	57	54	Gate Diameter, in. .050
Compression Set 70'/212°F., %	81	81	69	67	26	23	

Nitrile

Type of Curing System	Sulfur N158 Compression 30"/307°F.	Sulfur N158 Injection 2"/400°F.	Sulfur Donor Methyl Tuads N154 Compression 30"/307°F.	Sulfur Donor Methyl Tuads N154 Injection 2"/400°F.	Peroxide N158-2 Compression 30"/307°F.	Peroxide N158-2 Injection 2"/400°F.	Injection Molding Conditions
Tensile psi	2300	1930	1730	1950		Premature cure @ 350°F.	Cylinder Temperature °F. 200
Modulus @ 300% E. "	1260	870	1480	1640			Inject Pressure psi 1200
Elongation, %	500	480	365	325			" Time sec. 7.5
Hardness, Shore A	55	54	59	63			Gate Diameter, in. .050
Compression Set 70'/212°F., %	62	77	19	23			

Styrene/Butadiene

Type of Curing System	Sulfur S150 Compression 30"/307°F.	Sulfur S150 Injection 2"/400°F.	Sulfur Donor Tetrone A-Captax S150-1 Compression 30"/307°F.	Sulfur Donor Tetrone A-Captax S150-1 Injection 2"/400°F.	Peroxide S150-2 Compression 30"/307°F.	Peroxide S150-2 Injection 2"/350°F.	Injection Molding Conditions
Tensile psi	3230	3140		Cured in runner and sprue system	3050	2670	Cylinder Temperature °F. 190
Modulus @ 300% E. "	1390	1130			1300	1670	Inject Pressure psi 1500
Elongation, %	520	610			520	420	" Time sec. 10
Hardness, Shore A	59	63			63	66	Gate Diameter, in. .050
Compression Set 70'/212°F., %	71	68			16	59	

Silicone

	G11-1 No Post Cure Press 10"/340°F.	G11-1 No Post Cure Inject 2"/400°F.	G11-1 Post Cured 24' @ 480°F. Press 10"/340°F.	G11-1 Post Cured 24' @ 480°F. Inject 2"/400°F.	G11-2 No Post Cure Press 10"/340°F.	G11-2 No Post Cure Inject 2"/400°F.	G11-2 Post Cured 24' @ 480°F. Press 10"/340°F.	G11-2 Post Cured 24' @ 480°F. Inject 2"/400°F.	Injection Molding Conditions
Tensile psi	680	630	670	550	760	640	800	770	Cylinder Temperature °F. RT
Modulus @ 300 % "	460	480	400	500	630	-	700	-	Inject Pressure psi 700
Elongation, %	420	390	390	340	370	270	370	285	" Time sec. 6
Hardness, Shore A	47	45	44	43	54	56	57	58	Gate Diameter, in. 0.100
Compression Set 70'/212°F., %	7	7	6	5	19	20	13	10	

TABLE V

THE EFFECT ON SBR PHYSICAL PROPERTIES OF REDUCING THE INJECTION MOLDING CYCLE TO ONE MINUTE OR LESS

Sulfur-Santocure S150

	Press Cured 30"/307°F.	Injection Molded @ 400°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.
Tensile psi	3230	2410	2980	3170	3140
Modulus @ 300% E. "	1390	650	970	1160	1130
Elongation, %	520	705	630	600	610
Hardness, Shore A	63	60	61	63	63
Compression Set 70'/212°F., %	63	Spongy	92	84	68

Cylinder Temperature °F. 200
Injection Pressure psi 1200
" Time sec. 14
Gate Diameter in. .050

Sulfur-Altax-Methyl Selenac S150-3

	Press Cured 30"/307°F.	Injection Molded @ 400°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.	2 Min.
Tensile psi	1590	2170	2080	2350	2160	2210
Modulus @ 300% E. "	1470	1220	1360	1310	1330	1280
Elongation, %	210	280	275	285	270	280
Hardness, Shore A	70	67	65	66	68	69
Compression Set 70'/212°F., %	25	58	53	40	36	30

Cylinder Temperature °F. 200
Injection Pressure psi 1300
" Time sec. 14
Gate Diameter in. .050

Sulfur-Santocure-Morfax S150-4

	Press Cured 30"/307°F.	Injection Molded @ 400°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.	2 Min.
Tensile psi	3160	3410	3240	3120	3100	2760
Modulus @ 300% E. "	900	1020	920	880	790	730
Elongation, %	700	730	720	720	755	710
Hardness, Shore A	63	61	61	62	62	62
Compression Set 70'/212°F., %	63	80	77	74	68	64

Cylinder Temperature °F. 200
Injection Pressure psi 1500
" Time sec. 10
Gate Diameter in. .060

Sulfur-Santocure-Ledate S105-5

	Press Cured 30"/307°F.	Injection Molded @ 380°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.	2 Min.
Tensile psi	2870	2580	2720	2070	2540	2960
Modulus @300% E. "	1620	1450	1430	1500	1500	1380
Elongation, %	295	295	300	245	280	310
Hardness, Shore A	72	67	67	67	68	69
Compression Set 70'/212°F., %	37	65	49	48	43	37

Cylinder Temperature °F. 200
Injection Pressure psi 1500
" Time sec. 15
Gate Diameter in. .060

Sulfur-Santocure (Cadmium Oxide) S150-7

	Press Cured 30"/307°F.	Injection Molded @ 400°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.	2 Min.
Tensile psi	3020	3040	3100	3010	2770	2740
Modulus @ 300% E. "	2211	1820	2130	2240	2590	2370
Elongation, %	370	460	420	375	340	335
Hardness, Shore A	68	64	65	65	68	67
Compression Set 70'/212°F., %	49	67	62	53	42	37

Cylinder Temperature °F. 200
Injection Pressure psi 1500
" Time sec. 12
Gate Diameter in. .060

Sulfur-Santocure (Cadmium Oxide) S150-7

	Press Cured 30"/307°F.	Injection Molded @ 420°F. 1/2 Min.	3/4 Min.	1 Min.	1-1/2 Min.	2 Min.
Tensile psi	3020	2220	2100	1880	2260	1530
Modulus @ 300% E. "	1060	1100	1240	1160	1120	1130
Elongation, %	370	290	260	250	280	230
Hardness, Shore A	68	66	66	66	66	66
Compression Set 70'/212°F., %	49	57	46	44	33	27

Cylinder Temperature °F. 200
Injection Pressure psi 1500
" Time sec. 12
Gate Diameter in. .060

those molded by compression for 30 minutes, however, an injection molding cycle of one to two minutes was required in order to obtain compression set values equivalent to those of compression molded samples. The compound which employed cadmium oxide in place of zinc oxide displayed the best over all properties for short cycles. At a cure temperature of 420°F., samples injection molded for 90 seconds had properties equal to those of compression molded samples, including compression set.

The incorporation of coagents, tri allyl cyanurate and di allyl adipate into peroxide cured Genthane S compounds resulted in improved properties, as shown in Table VI. The use of coagents in Genthane SR compounds resulted in slightly poorer properties. This is possibly due to incompatability between the coagent and the TDI dimer required to give Genthane SR improved oil and water resistance.

During the course of this investigation, several orders for production quantities of end items were received, which if filled by injection molding would result in a reduction in cost and time required to complete the orders.

Compounds were prepared and test pads injection molded to determine their conformance to grade requirements of Specification MIL-R-3065 and MIL-STD-417. Physical properties and grade requirements are presented in Table VII. Cure cycles of 2-3 minutes at 400°F. were usually sufficient to produce rubber meeting all the requirements of the specified grades. No difficulty was encountered in meeting the dimensional requirements with injection molded articles. The following dimensional tolerances were required for the filler gasket, item D of Figure 2.: Outside diameter - .004 inches, inside diameter +.003 inches and +.005 inches for thickness. These tolerances were unusually close for molded rubber items. Dimensions of injection molded articles can be controlled to a limited degree by changing injection pressure and/or injection cylinder temperature. Photographs of end items produced by injection molding are presented in Figures 2 and 3.

Some difficulty with air entrapment was experienced during the injection molding of end items, but changes in mold design eliminated this problem. The first molds made for injection molding of more intricate shapes than flat test pads, were made with close fitting sections in order to minimize flash. It was discovered that the close fit would not allow air to escape fast enough and some air became trapped by the incoming rubber. Modifications of the molds to provide more space between mating surfaces eliminate air entrapment but increased the amount of flash.

TABLE VI

EFFECTS OF CO.-AGENTS ON PHYSICAL PROPERTIES
OF INJECTION MOLDED URETHANE VULCANIZATES

Genthane S U27-2 DiCup 40C Cure

	Press Cured	Injection Molded @ 350°F.					
	30"/320°F.	1 Min.	1-1/2 Min.	2 Min.	2-1/2 Min.	3 Min.	
Tensile psi	3810	2900	3360	3490	3465	3240	Cylinder Temperature °F. 190
Modulus @ 300% E. "	1300	700	1200	1440	1610	1660	Injection Pressure psi 1700
Elongation, %	600	835	650	580	522	490	" Time sec. 30
Hardness, Shore A	57	57	62	63	63	63	Gate Diameter in. .070
Compression Set 70'/212°F., %	80	94	80	73	64	63	

Genthane S U27-3 DiCup 40C + Tri Allyl Cyanurate Cure

	Press Cured	Injection Molded @ 360°F.					
	30"/320°F.	1 Min.	1-1/2 Min.	2 Min.	2-1/2 Min.	3 Min.	
Tensile psi	2600	2530	2130	2240	2390	2420	Cylinder Temperature °F. 170
Modulus @ 300% E. "	1100	720	980	1370	1370	1510	Injection Pressure psi 1500
Elongation, %	290	405	310	255	265	270	" Time sec. 19
Hardness, Shore A	65	65	67	70	71	71	Gate Diameter in. .100
Compression Set 70'/212°F., %	35	65	56	43	36	35	

Genthane S U27-4 DiCup 40C + Di Allyl Adipate Cure

	Press Cured	Injection Molded @ 360°F.					
	30"/320°F.	1 Min.	1-1/2 Min.	2 Min.	2-1/2 Min.	3 Min.	
Tensile psi	2930	3020	3210	3290	3050	3130	Cylinder Temperature °F. 165
Modulus @ 300% E. "	2010	1400	1880	2110	2350	2440	Injecticn Pressure psi 1500
Elongation, %	400	570	455	435	370	380	" Time sec. 18
Hardness, Shore A	62	60	64	66	67	67	Gate Diameter in. .100
Compression Set 70'/212°F., %	46	72	57	47	45	42	

Genthane SR U27 DiCup 40C Cure

	Press Cured	Injection Molded @ 350°F.					
	30"/320°F.	1 Min.	1-1/2 Min.	2 Min.	2-1/2 Min.	3 Min.	
Tensile psi	4230	2990	3660	3880	4190	4130	Cylinder Temperature °F. 190
Modulus @ 300% E. "	1350	730	990	1400	1600	1760	Injection Pressure psi 1700
Elongation, %	585	780	770	620	590	545	" Time sec. 30
Hardness, Shore A	63	57	58	64	64	64	Gate Diameter in. .070
Compression Set 70'/212°F., %	76	90	75	72	62	54	

Genthane SR U27-1 DiCup 40C + Tri Allyl Cyanurate Cure

	Press Cured	Injection Molded @ 350°F.					
	30"/320°F.	1 Min.	1-1/2 Min.	2 Min.	2-1/2 Min.	3 Min.	
Tensile psi	3360	2980	3020	3750	4080	3860	Cylinder Temperature °F. 190
Modulus @ 300% E. "	2920	690	810	1010	1630	2340	Injection Pressure psi 1600
Elongation, %	315	805	705	750	585	420	" Time sec. 24
Hardness, Shore A	67	58	59	61	63	65	Gate Diameter in. .070
Compression Set 70'/212°F., %	29	95	89	77	70	53	

TABLE VII

PROPERTIES OF INJECTION MOLDED RUBBER TO MEET REQUIREMENTS OF MIL-R-3065 & MIL-STD-417, GRADE RS $415BC_1F_1K_1$

SBR 1500 S154-4

Original Properties	Press 30"/307°F.	Injection Molded @ 400°F. 1 Min.	2 Min.	3 Min.	4 Min.	5 Min.	Requirements MIL-R-3065 & MIL-STD-417 Grade $415BC_1F_1K_1$
Tensile psi	1910	1790	1700	1810	1640	1900	1500 Min.
Modulus @ 300% E. "	710	530	560	530	540	550	
Elongation, %	495	540	510	570	530	570	400 Min.
Hardness, Shore A	49	45	45	44	44	44	40 ± 5
Aged 70'/158°F./ Air							
Tensile % Change	-4	-16	+1	+15	+21	+22	-25 Max.
Elongation "	-5	-29	-5	-6	+3	+9	-25 Max.
Hardness, Points "	+2	+4	+3	+3	+2	+2	+7 Max.
Comp. Set., %	18	37	31	23	19	20	25 Max.
Resistance to Ozone							
ASTM D1149 Bent Loop Specimen	OK	OK	OK	OK	OK	OK	No Cracks
ASTM D746 @ -40°F.	Pass	Pass	Pass	Pass	Pass	Pass	No Failures
Adhesion to Steel							
ASTM D429 lbs./in. Width Method B	56	-	43	50	72	80	40 Min.

Nitrile N154

Original Properties	Press 30"/307°F.	Injection Molded @ 400°F. 1 Min.	2 Min.	3 Min.	4 Min.	5 Min.	Requirements MIL-R-3065 MIL-STD-417 Grade $SC615A_1B_1E_3F_2$
Tensile psi	1730	1750	1950	1660	1820	1850	1500 Min.
Modulus @ 300% E. "	1480	1640	1640	1570	1720	1610	
Elongation, %	365	320	325	320	325	330	300 Min.
Hardness, Shore A	59	63	63	64	63	63	60 ± 5
Aged 70'/212°F./Air							
Tensile % Change	+16	0	-7	+19	+8	+7	-15 Max.
Elongation "	-11	-38	-20	-9	-15	-12	-35 Max.
Hardness, Points "	+3	+9	+3	+3	+4	+3	+15 Max.
Comp. Set., %	19	34	23	16	15	12	+35
Aged 70'/212°F./#3 ASTM Oil							
Tensile % Change	-11	-29	-39	-16	-25	-24	-65 Max.
Elongation "	-19	-36	-37	-25	-28	-26	-50 Max.
Volume "	+34	+40	+43	+40	+43	+42	0 to 120%
ASTM D746 @ -67°F.	Pass	Pass	Pass	Pass	Pass	Pass	No Failures

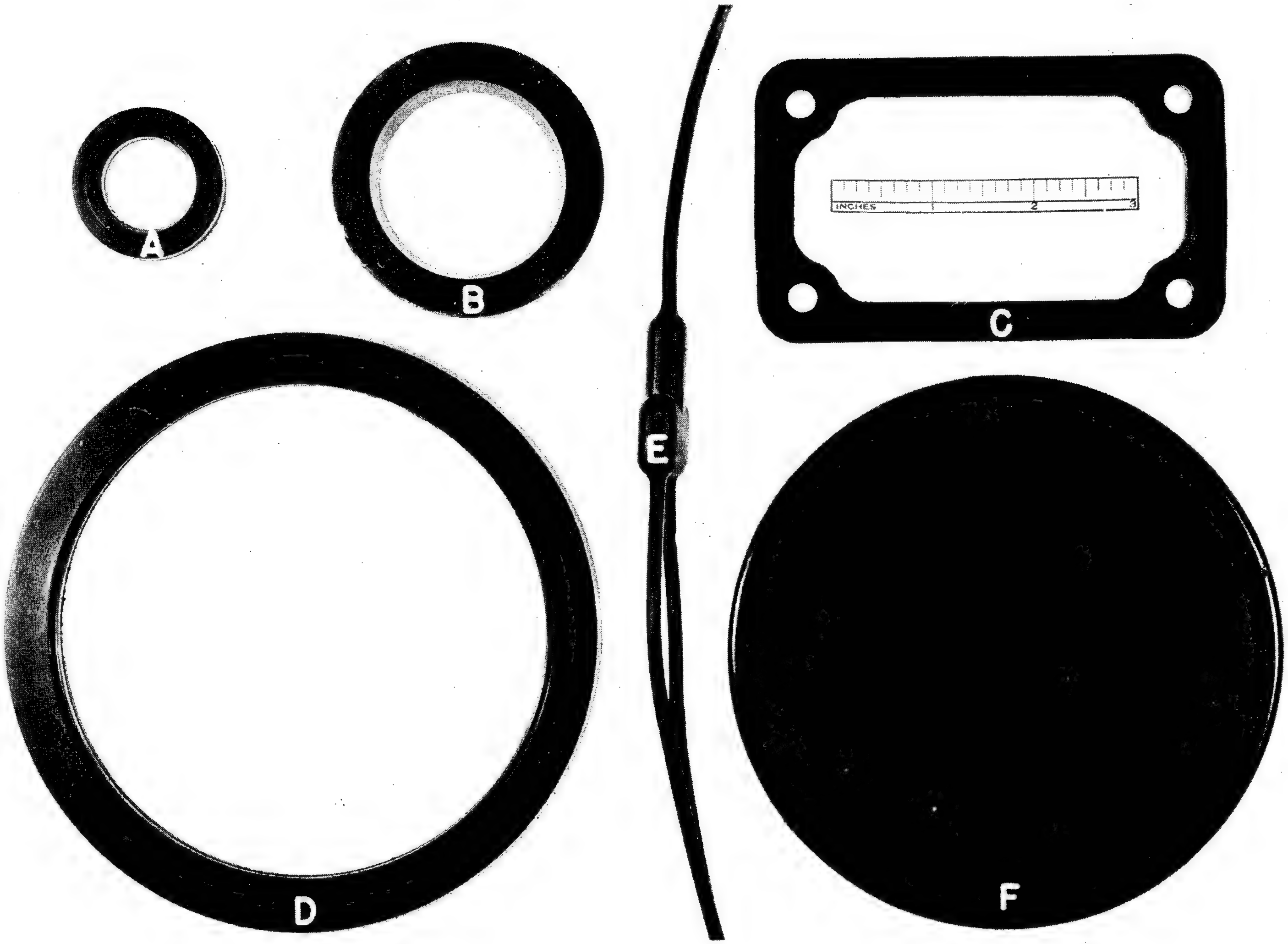

FIG. 2

INJECTION MOLDED END ITEMS

A - Recoil Packing. B - Piston Wiper Dwg. No. 10954481. C - Missile Gasket Dwg. No. 8022002. D - Filler Gasket Dwg. No. 8427067. E - Cable Closure Dwg. No. B8383633. F - Test Pad.

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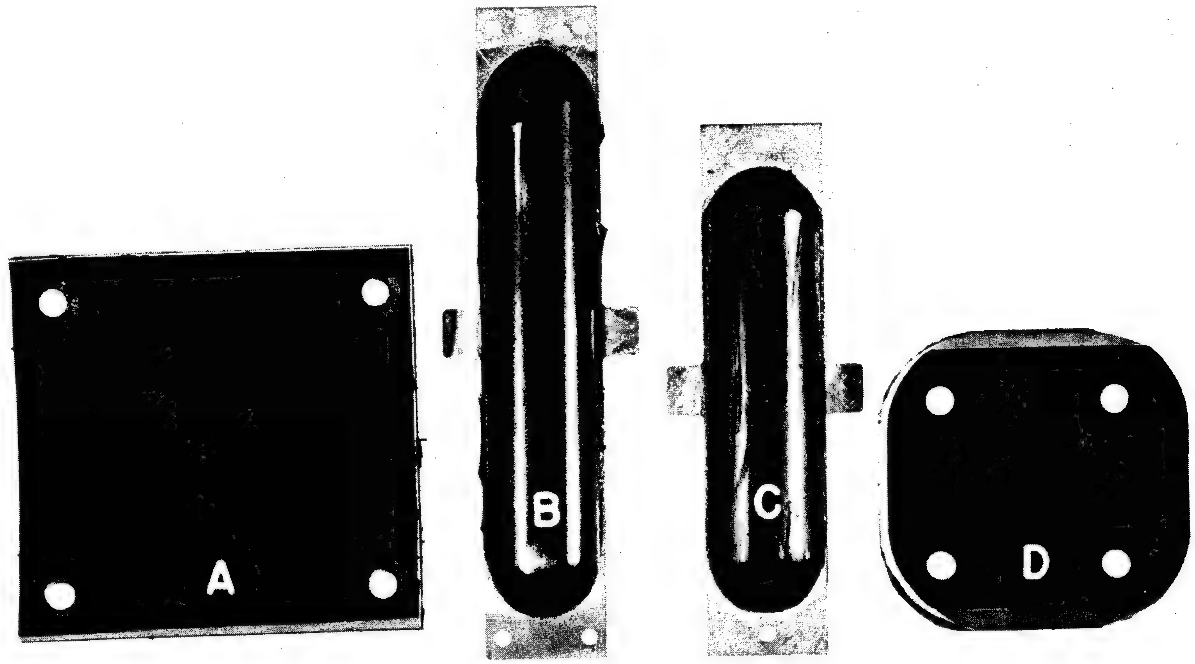

FIG. 3

INJECTION MOLDED END ITEMS
A - Pad Assembly Dwg. No. C8427094. B & C - Shipping Clamps Dwg. No. 10936852. D - Pad Assembly Dwg. No. 8426932.
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Several of the grade requirements specified that the rubber be bonded to metal (See Figure 3) during the vulcanization process. Rubber to metal bonding during injection molding presented conditions not normally encountered during compression molding. The force at which the rubber enters the mold plus the flow of rubber in filling the cavity had a tendency to wipe the bonding agent from the surface of the metal plates. The high mold temperature (400°F.) also contributed to the problem by producing a partial cure in the bonding agent before the mold filled.

A number of bonding agents were evaluated on steel plates using both a one and two coat system. Results are listed in Table VIII. A two coat system was required to provide adequate bond strengths. Diluting the components of the two coat system with suitable solvents produced some improvement. Adequate bond strengths were obtained using a primer coat diluted 1:1 with toluene and a cover coat undiluted. Using the above two coat system on anodized aluminum produced bonds which were stronger than the bonded rubber.

CONCLUSIONS

Most elastomeric compounds which can be successfully compression molded can be injection molded.

The sulfur donor cure system using methyl tuads produced the best over all properties for sulfur curable, injection molded compounds.

End items can be produced which have physical properties and dimensional tolerances equivalent to those of compression molded articles.

The successful injection molding of elastomeric items depends to a large extent on proper mold design.

The injection molding process in some cases is better suited for production items than compression molding. The mold for the cable closure assembly (Figure 2) was simpler to make for injection molding than for compression molding.

RECOMMENDATIONS

Injection molding of rubber items should be considered as a means of producing articles on a production basis. This method offers high quality articles at considerable reduction in rejected pieces, cost of operation and handling time.

TABLE VIII

EVALUATION OF BONDING AGENTS USED WITH INJECTION MOLDING

SBR 1500 S154-4 Bonding Agent	Press Cured 30"/307°F. lbs./in. Width	ASTM D429 Method B Injection Molded @ 400°F. lbs./in. Width 2 Min.	3 Min.	4 Min.	5 Min.
Adhesion to Steel					
Chemlok 220	34	36	6	1	3
" 203		No Bond			
Chemlok 220 Diluted					
1:1 Toluene		6			
1:2 "		5			
1:3 "		5			
Chemlok 220/203					
203 Diluted 1:1 Mek.		49			
" 1:2 "		13			
1:3 "		10			
Chemlok EX 500-1		37			
Ty Ply UP		No Bond			
" BN		"			
" S		16			
Thixon F-6		No Bond			
" P-4		"			
Chemlok 220 Undiluted over					
" 203 Diluted 1:1 Mek.	56	43	50	72	80
Adhesion to Anodized Aluminum					
Chemlok 220/203			106 (Rubber Failed)		

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The injection molding process for elastomers was investigated for its applicability in the fabrication of end items for Army use. A variety of elastomeric compounds was prepared and injection molded. Results indicate that most compounds which can be compression molded can also be injection molded. Rubber items having equivalent physical properties and dimensions were obtained from the two molding processes. Injection molding reduces the time required for curing; eliminates the need to perform the rubber prior to molding, reduces the amount of mold handling; and lowers the rejection rate in comparison with compression molding.

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